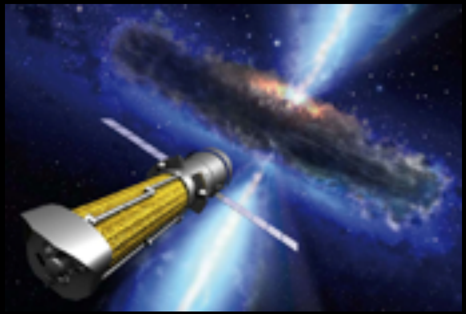
Structure Formation
IXO synergies with the E-ELT and Euclid

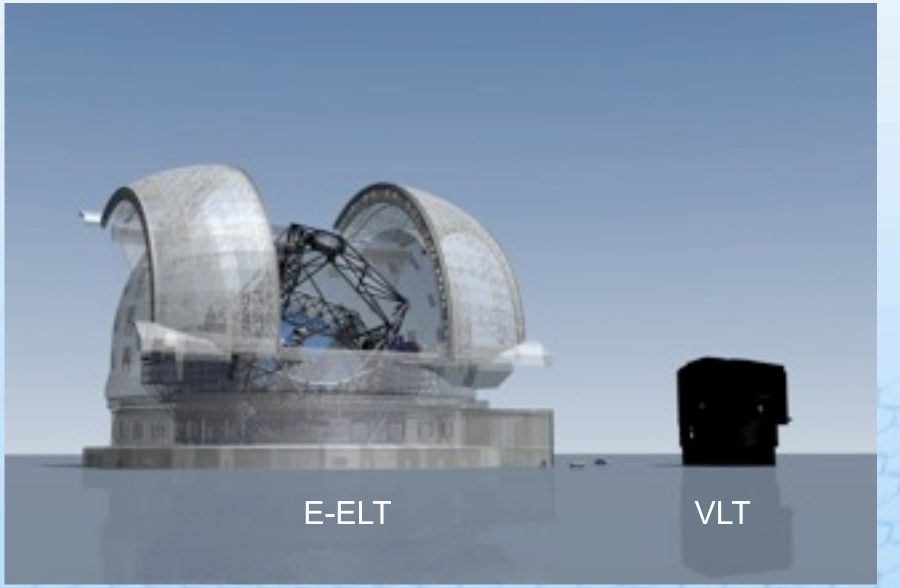
Piero Rosati (ESO)

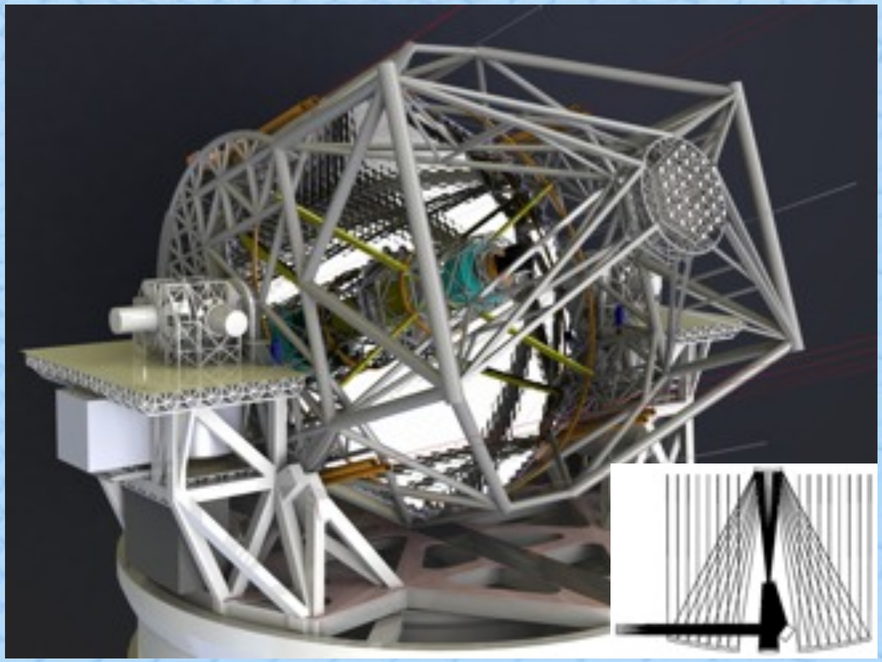


IXO Science Meeting, 28 Apr 2010

The European Extremely Large Telescope (E-ELT)

- The E-ELT will be the largest optical telescope in the world, with its 42m primary segmented mirror (22m GMT, 30m TMT). Collecting area ~2x all 8-10m telescopes! Diffraction limit: 10 mas at 2μ
- Science goals take advantage of the high spatial resolution (5 mas in the J-band) and immense collecting area. Synergies with JWST, ALMA, ...
- Overall requirements driven by major science cases (exo-planets, stellar pops, galaxy formation, cosmology)
- Telescope structure: Nasmyth design (nearly 5000 tons of steel). Dome of 100m footprint, 80m high.
- Novel optical design: 5 mirrors in a folded three-mirror anastigmatic design including adaptive optics
- Instrumentation: up to ten focal stations, FoV 10’
- Cost: construction ~1 billion Euros (incl. instrumentation), operations ~35 millions/year
- Status: detailed design phase until end of 2010, construction proposal to be reviewed by Council in Q4/10, construction phase of 7 years
- Site: Armazones (Chile, 3000m, ~40 km east of Paranal) just selected !





ESO
European Organisation for Astronomical Research in the Southern Hemisphere

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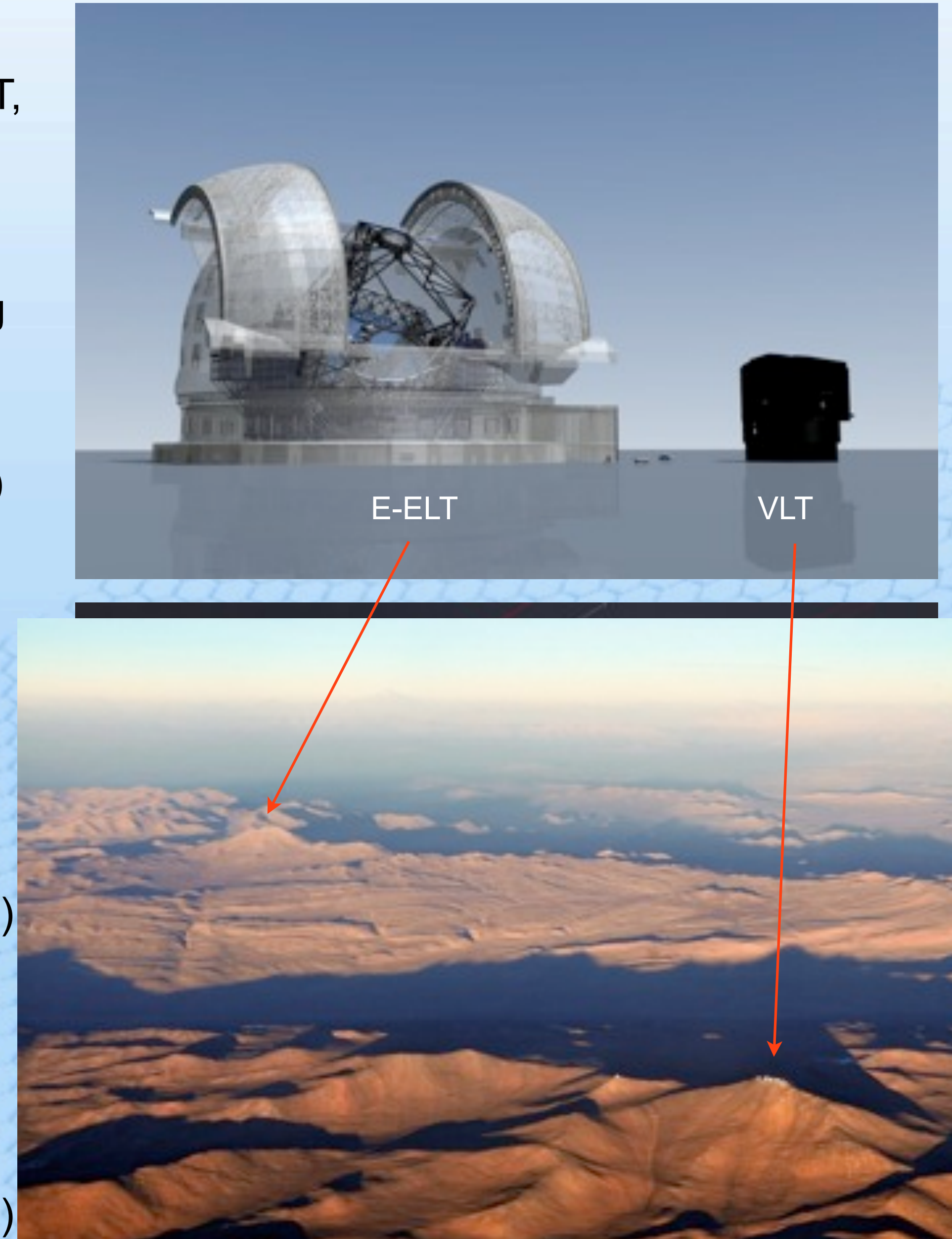

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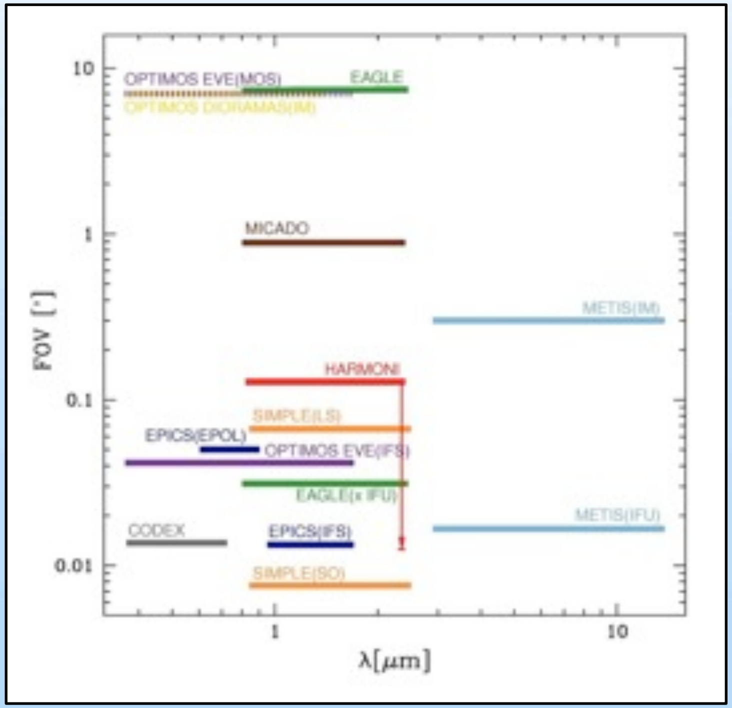
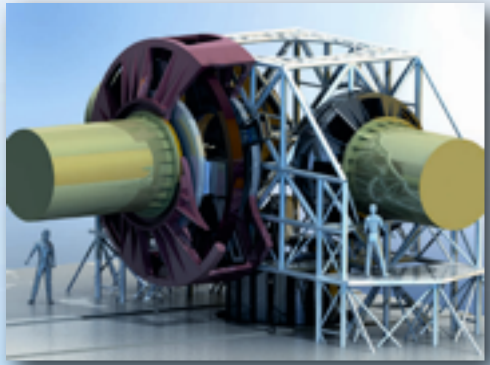
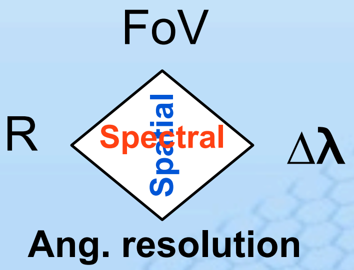
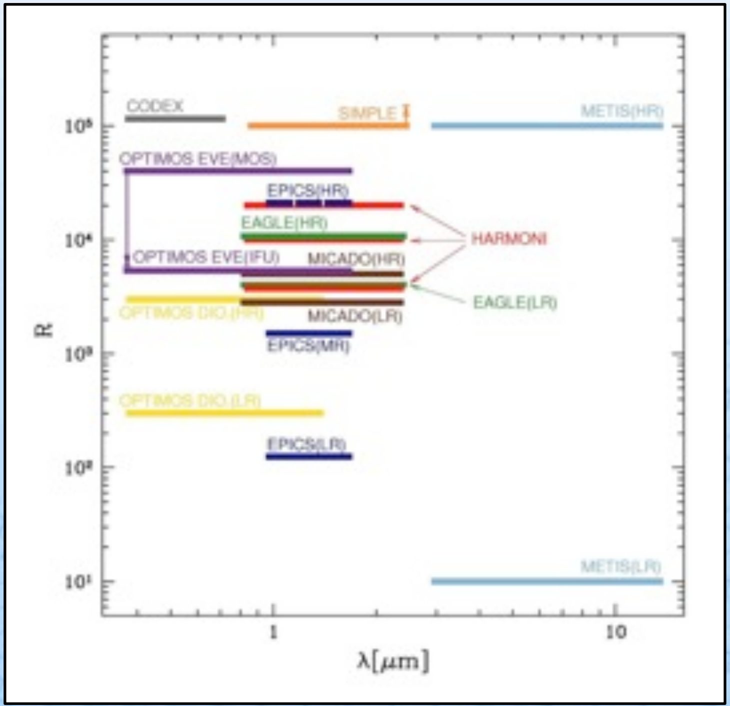
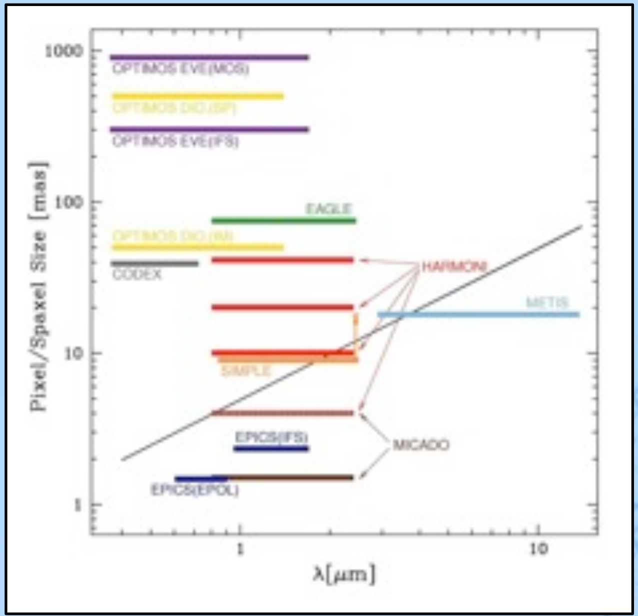
Instrumentation



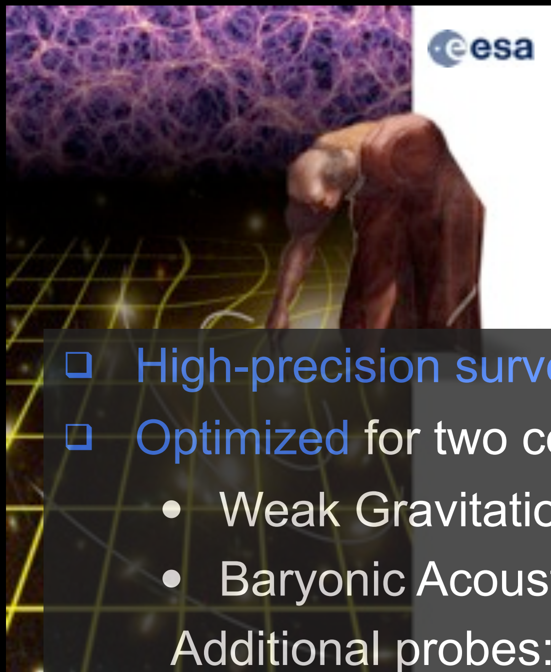




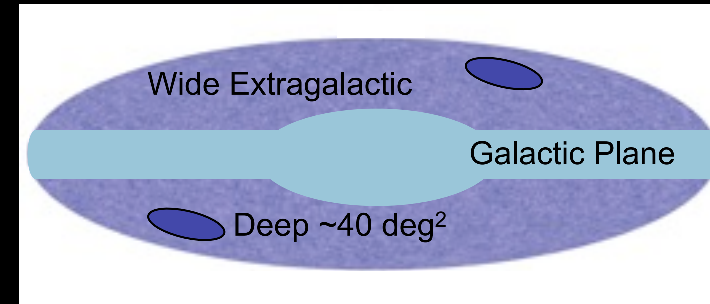




- To cover a wide spectroscopic and spatial discovery space
- Ten Phase A Instrumentation studies nearing completion
- 2 to 3 instruments to be selected at first light
- 5 to 6 instruments to be built for the first decade suite

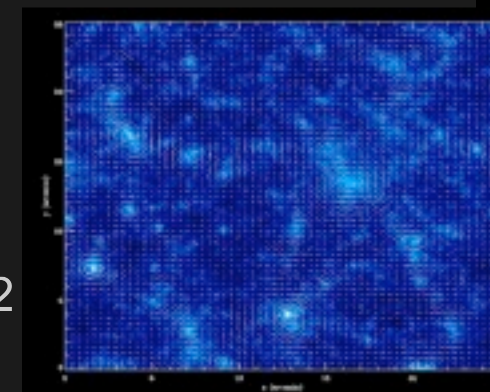


Euclid

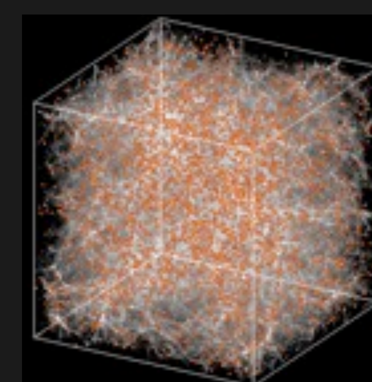


- High-precision survey mission to map the geometry of the Dark Universe
- Optimized for two complementary cosmological probes:
  - Weak Gravitational Lensing
  - Baryonic Acoustic Oscillations

  Additional probes: clusters, redshift space distortions, ISW



- Full extragalactic sky survey (20,000 deg^2) with 1.2m telescope at L2
  - Imaging (PI: A.Refregier):
    - High precision imaging at visible wavelengths, $RIZ_{AB} \leq 24.5$ (AB, 10σ)
    - Photometry/Imaging in the near-infrared, Y, J, H ≤ 24 (AB, 5σ), photo-z's [$\Delta z \lesssim 0.05(1+z)$] with ground based complement (PanStarrs-2, LSST etc)
  - NIR Spectroscopy (PI: A.Cimatti)
    Slitless survey, 1-2 μ, R=300-500 (emission line objects)
    to $H_{AB}<22$, $F_{H\alpha} > 4\times10^{-16}$ cgs (7σ), $0.5<z<2$
    ≈70 million galaxies & AGNs (3D View out to z~2), >70x SDSS



- Legacy science for a wide range of areas in astronomy
- Survey Data public after one year
- ESA Cosmic Vision 2020, downselected to definition/optimization phase, launch in 2018, if selected

Euclid
a gold mine for (obscured and unobscured) AGN

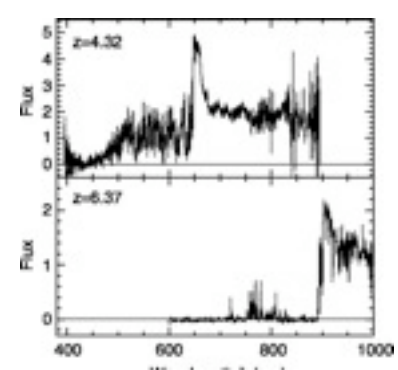
- About a few % of Euclid spectra will be AGN:
  ~ 10^6 of them ! - an order of magnitude more than the SDSS quasars

  These will cover a **very wide redshift range with at least two lines :**

	z range
Ha	0.52 - 2.0
Hβ + [OIII]	1.05 - 3.0
MgII	2.60 - 7.1
CIV	5.45 - 11.9
Lya	7.10 - 16.4

Two strong lines (CIV and Lyα) at 7.1 < z <11.9

- About equally split in type 1 (broad lines; easily recognizable from the spectra) and type 2 (narrow lines).
- Type 2's will be recognized on the basis of their [NII]/Ha ratio, some **~2 x 10^5 at 1<z<2** (3 order of mag gain compared to current samples!)
- Largest unbiased survey of high-z QSOs via Ly-break imaging and slitless spectroscopy (also from the Deep survey)

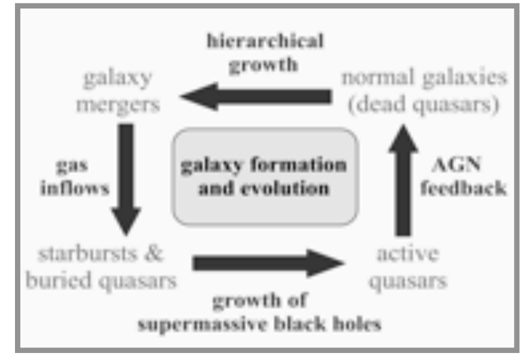


Growth of structure ⇔ SMBH growth

[several IXO science cases]

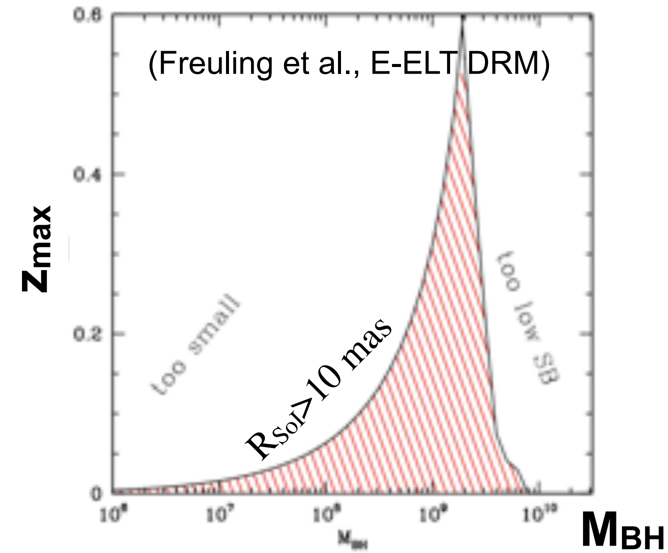
SMBHs play a critical role in the *growth* and *structure* of their host galaxies by modulating their star formation history via a strong physical coupling

Understanding scaling relations between M_{BH} and properties of their (active or dormant) host galaxies, σ, M_{*}, L



Role of E-ELT (IFU spectroscopy, 4 mas pixel, R~30 km/s, e.g. HARMONI instrument concept):

- Resolve the BH sphere of influence and measure directly BH masses with stellar kinematics, out to 20 Mpc for $M_{BH}>10^4\ M_{\odot}$ and out to z~0.5 for $10^9\ M_{\odot}$ BHs



$$R_{\rm SoI} = GM_{BH}/\sigma^2 = 4.3\,{\rm kpc}\frac{(M_{BH}/10^7 M_{\odot})}{(\sigma/100\,{\rm km/s})^2}$$

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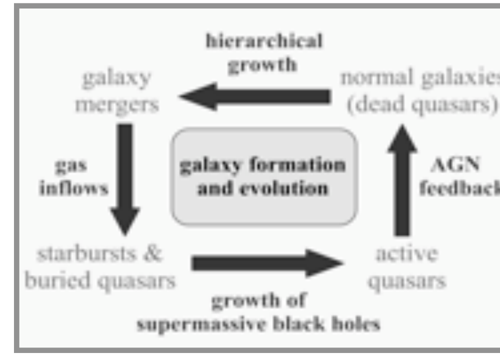

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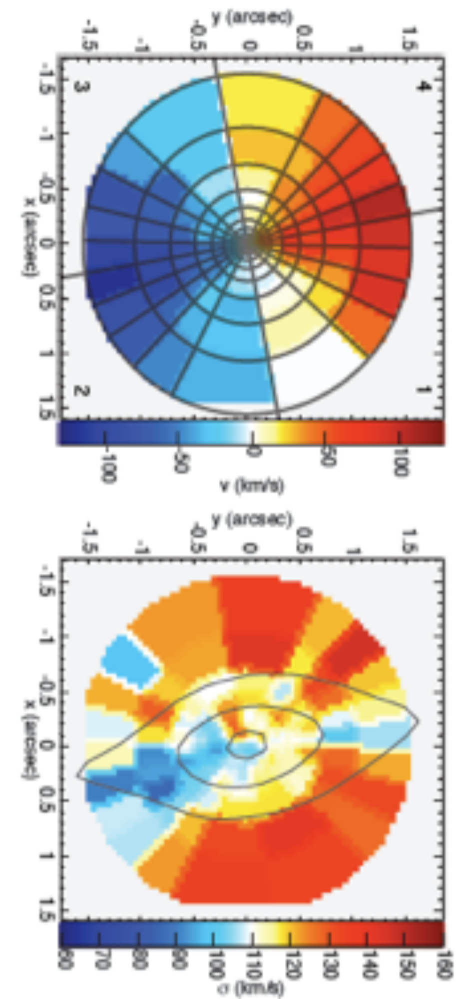
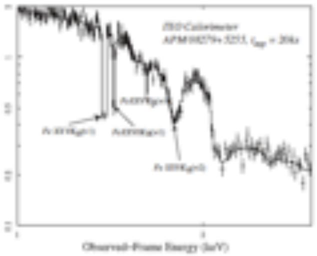
- In AGN host-galaxies, near the diffraction limit, the 3D data cube can be used to disentangle nuclear emission and measure the stellar σ of the host galaxy (CaT at z~1)
- BH masses for obscured BL AGN, selected from Euclid or IXO surveys, can be measured with the "virial method" [M_{BH}=f(FWHM,L_U)] using NIR lines (H_α,H_β at z=1-3)
- The local relation M_{BH}-σ, M_{BH}-M_{*} can be studied over 5 decades of M_{BH} for active and quiescent galaxies, its evolution traced for a range of obscurations (mitigation of selection effects).



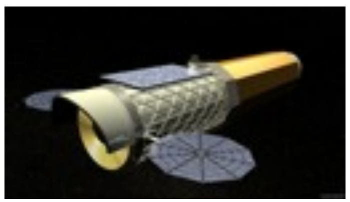
(Nowak et al. 07) NGC 4486a in Virgo with Sinfoni
$M_{BH}=1.3\times10^7\ M_\odot$, σ≈110 km/s

IXO-ELT-Euclid synergy flow

Galaxy-BH co-evolution



IXO



High R spectroscopy

- Kinematics of hot gas from spectral absorption features
- Feedback mechanisms at z~1-3
- BH accretion rates

E-ELT

Euclid

Vast reservoir of AGN for IXO, ELT follow-up

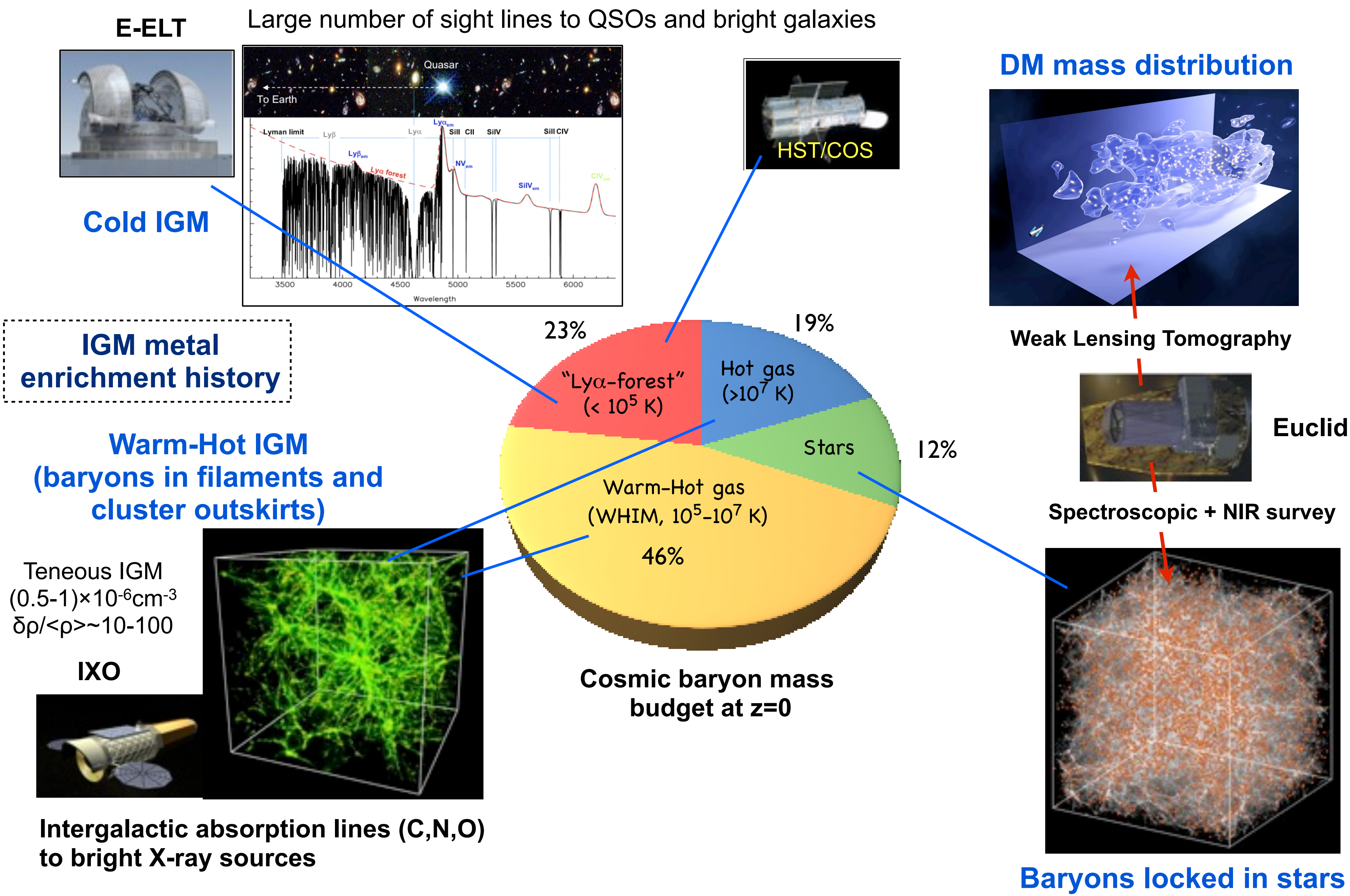
M_{BH}-σ-(M_{*},L) relation, evolution, scatter

- Direct dynamical BH masses by resolving the SoI out to z~0.5
- "AGN-free" imaging of hosts with IFUs
- "Virial" BH masses in NIR of IXO selected AGN over a broad range of redshifts, L_X and obscuration

M_{BH}, $\dot{M}_{BH}$, M_{*}, σ from z~0 to 3

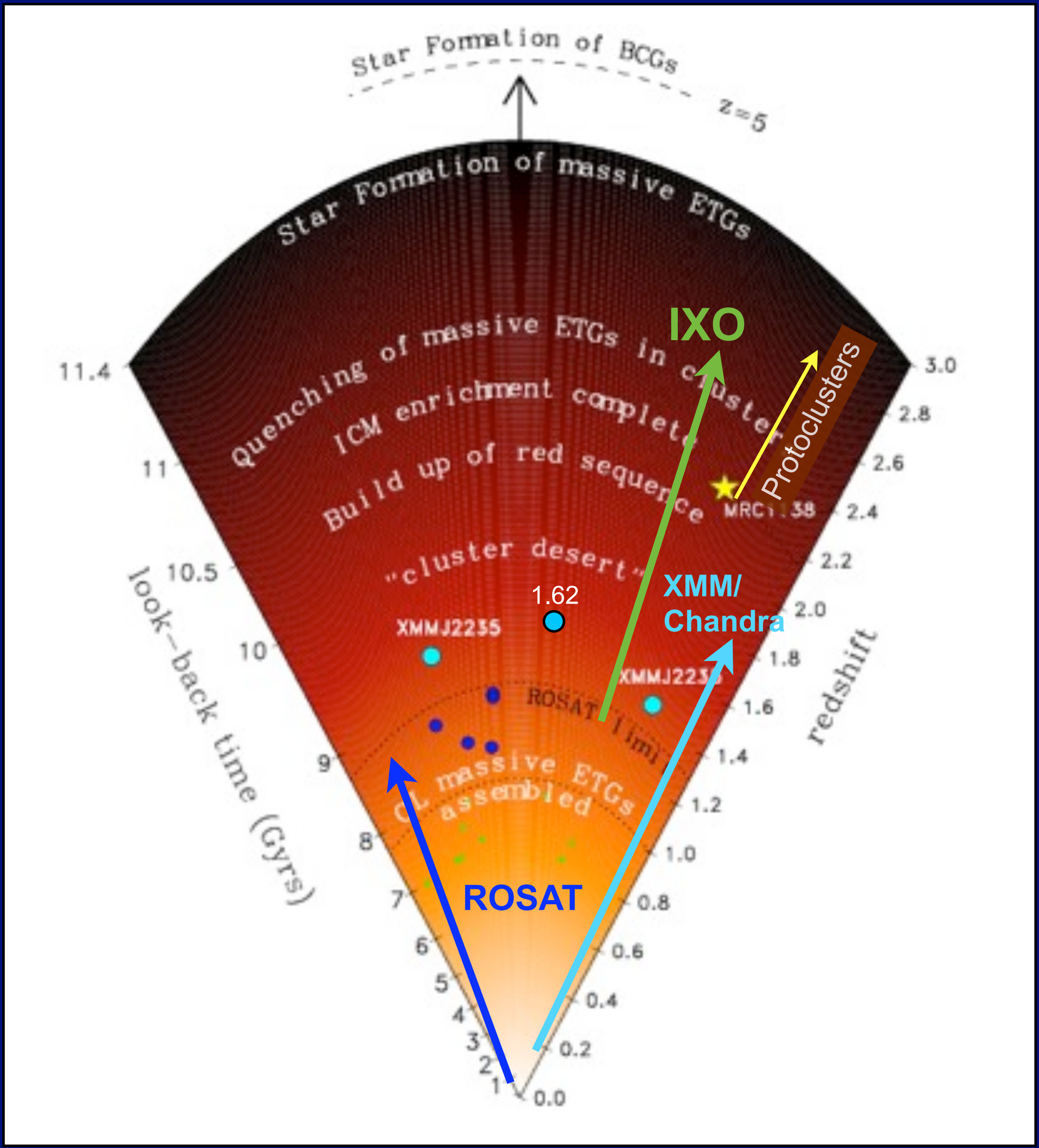
IXO-ELT-Euclid synergy flow

The Cosmic Web of Baryons (and Dark Matter)



Formation and Physics of proto-clusters

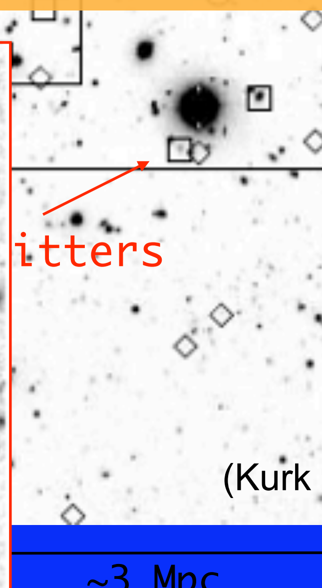
Cluster mass assembly history



- **Probing Hot and cold baryons at 1.5<z<2.5 is critical**

- The global SF rate and the BH mass accretion rate peak at z~2
- ≲50% of the stellar mass is assembled
- At z~2-3 proto-BCGs are expected to assemble via mergers of SB galaxies
- Proto-cluster regions accrete large amount of gas and start radiating in X-ray
- The first massive (~10^{14} $M_{\odot}$) virialized structures form (?)
- BHs hosted in merging galaxies coalesce and provide feedback energy release
- The morphology-density relation and the red sequence emerge

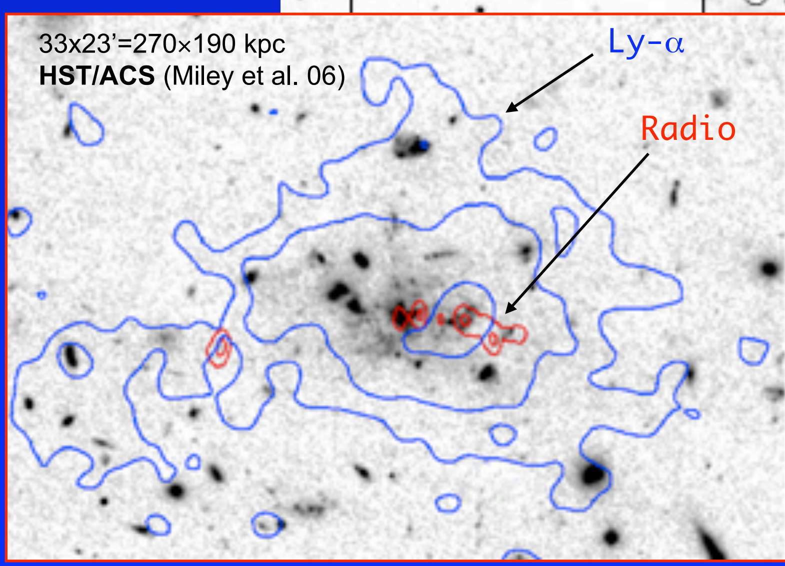
The Spiderweb proto-cluster complex (aka MRC1138-262) at z=2.16

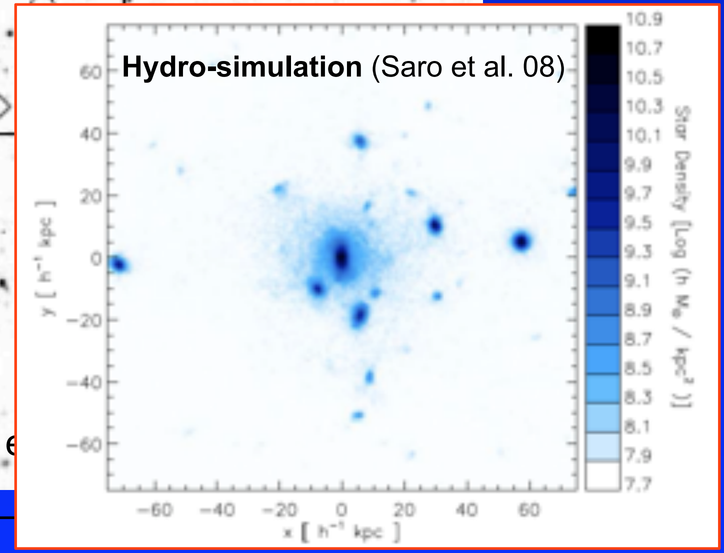


Most dramatic evidence of assembly of a massive cD galaxy in a forming proto-cluster region:

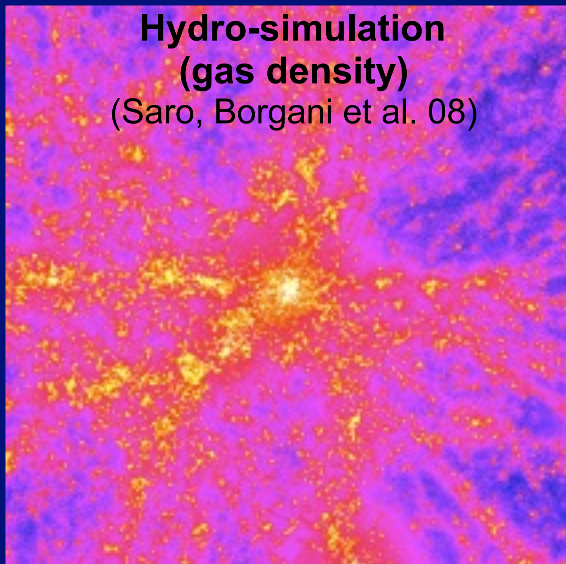
- Spectroscopically confirmed population of SF (30) + AGN (4) + overdensity of photometric passive members (nascent red sequence)
- Estimated total mass 1-4×10^{14} $M_\odot$
- Stellar mass of ~10^{12} $M_\odot$
- Complex dynamics with satellites v_{los}~10^3 km/s
- Diffuse UV intergalactic light
- Satellite galaxies SFR: 1-30 $M_\odot$/yr, total SFR~>500 $M_\odot$/yr
- 150 kpc Ly-α halo around the FRII RG

A comprehensive physical picture of aggregation and phase transformation of baryons require high S/N X-ray observations
⇒ **a clear niche for IXO**
(very expensive with Chandra, confusion limited with XMM)





Simulating protoclusters: mock observations of MRC1138

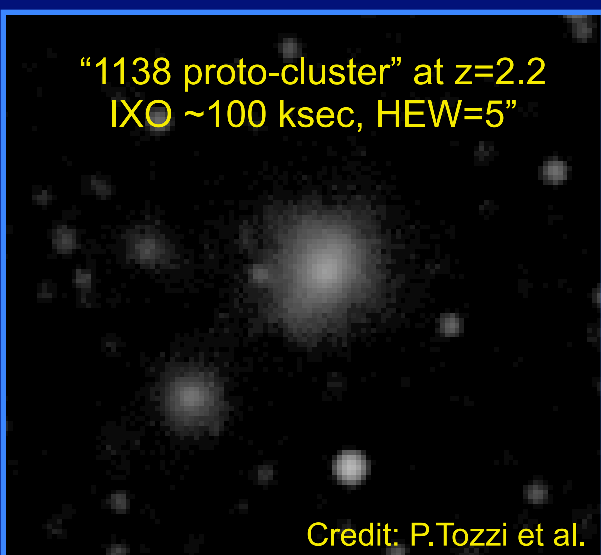


SN-wind and AGN feedback

$L_{0.5-2}$= 1-4×10^{44} erg s^{-1}

T_X=4-5 keV

Z_{Fe}= 0.4-0.5 Z_{sun}



Mock observations of the Spiderweb based on cosmological simulations (Saro et al. 08)

Cluster mass (M~10^{15} $M_\odot h^{-1}$ at z=0) and feedback tuned to “reproduce” Chandra (35 ks) and a range of optical observations

IXO ~100 ks observation of the Spiderweb yields ~10^4 cts

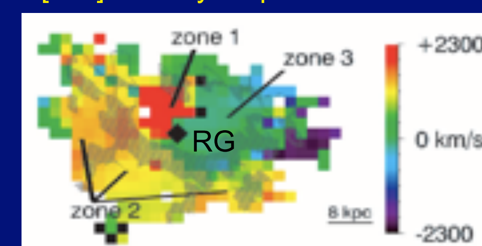
IXO: (good PSF essential)

- Disentangle thermal component from IC emission
- Entropy profile, T profile and mass, ICM metallicity
- Discriminate among a wide range of physical scenarios
- Shed light on feedback mode and source (AGN vs SNe)
- Coexistence of SF and nuclear activity in high density regions

ELT (IFU spectroscopy of BCG region):

- Kinematic gas map, outflows
- Metallicity of members galaxies
- Age dating stellar populations
- Complementary view of feedback

[OIII] velocity map with VLT/Sinfoni



Nesvadba et al. 08

Evidence of a kpc size outflow driven by the AGN

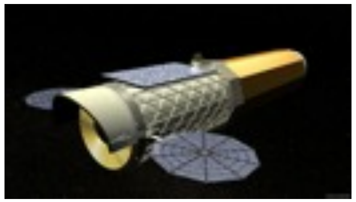
Search for protoclusters:

- High-z radio galaxies (z=2-5)
- Narrow-band searches
- Euclid limited at z<2
- X-ray require wide areas and depth (WFXT)

IXO-ELT-Euclid synergy flow

Formation of Protoclusters

IXO



Hot gas physics
Metallicity
Thermal vs non-thermal emission

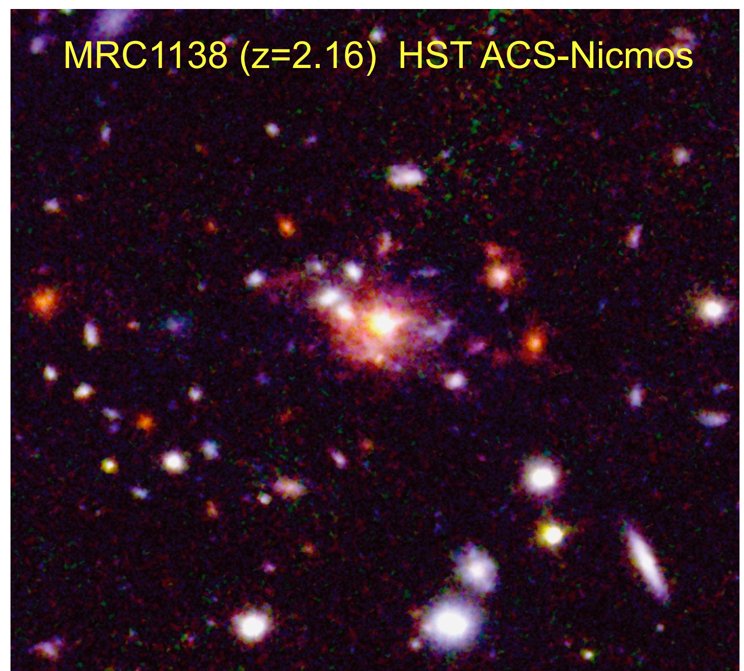
E-ELT

Gas & stellar kinematics
Feedback processes

Protocluster Formation

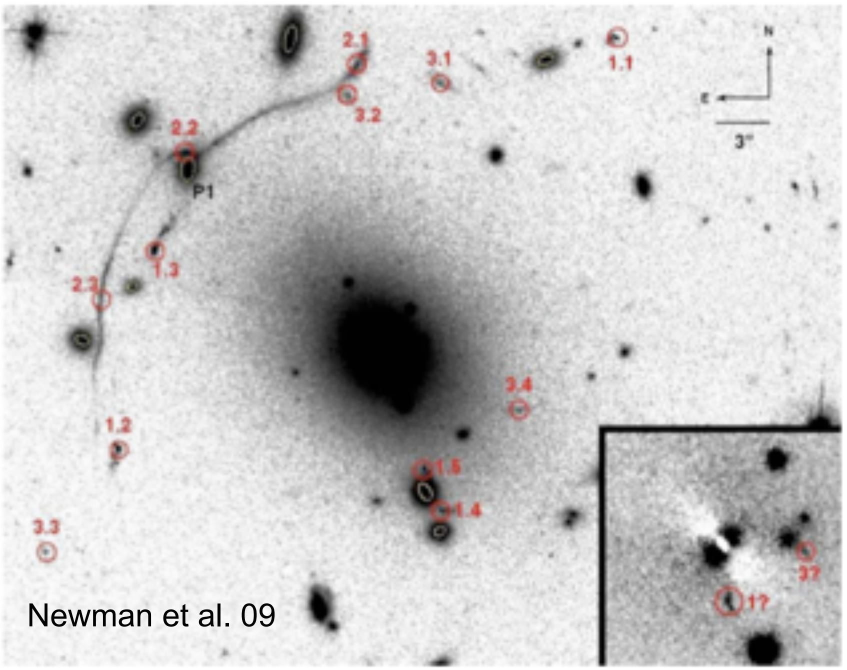
Euclid

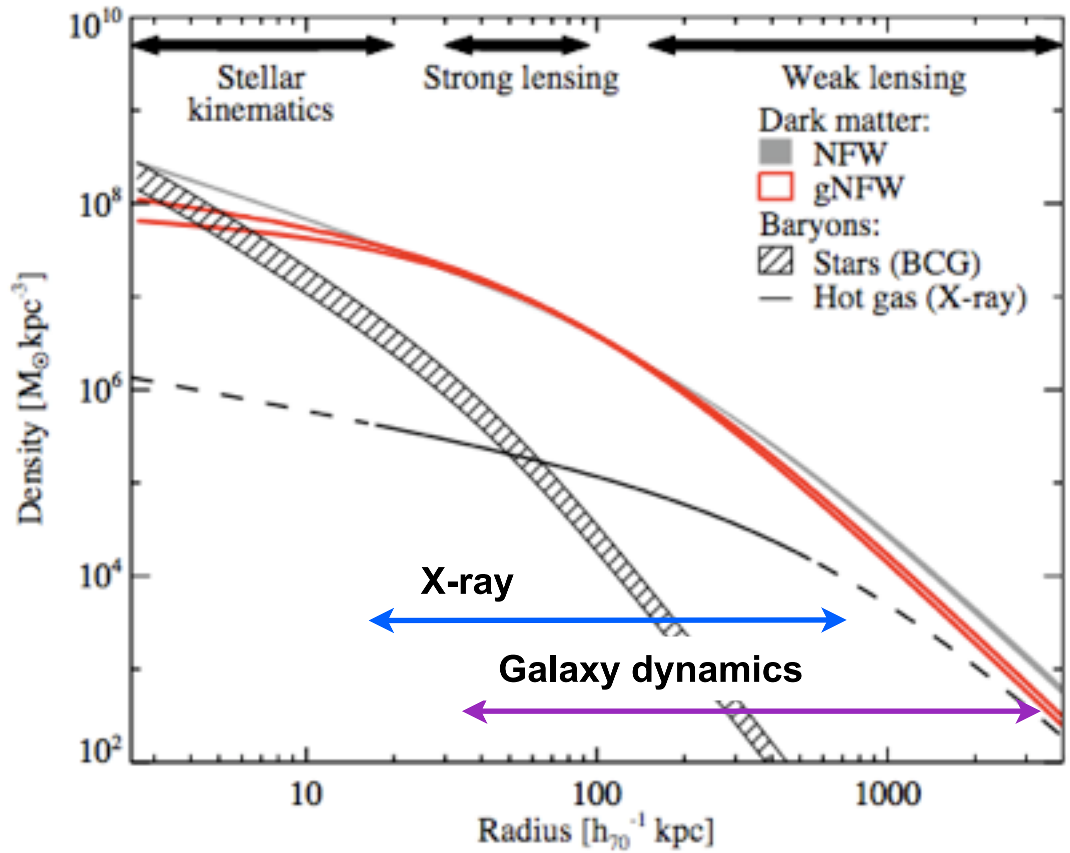
- Stellar masses
- NIR detection of >1000 $10^{13}\ M_{sun}$ at z>2
- Spectroscopy out of reach



DM and Baryon mass distribution in clusters

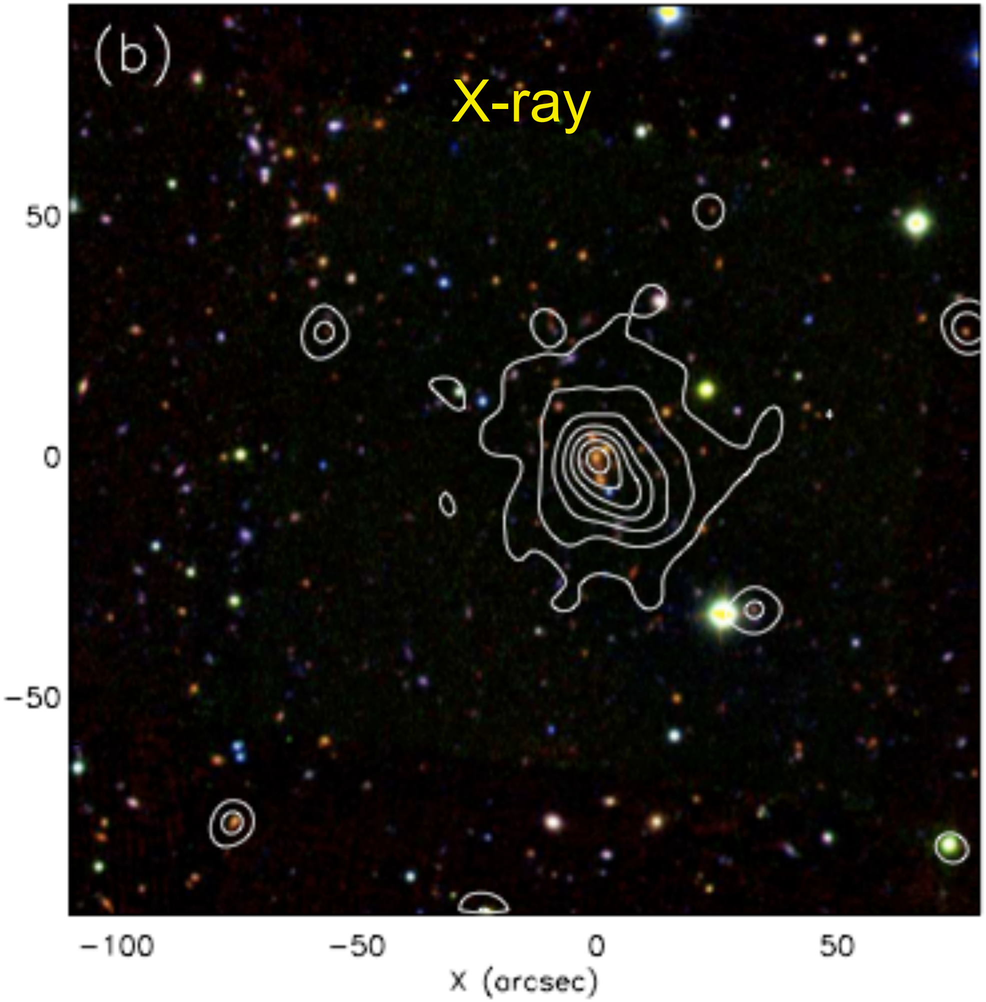
Abell 611

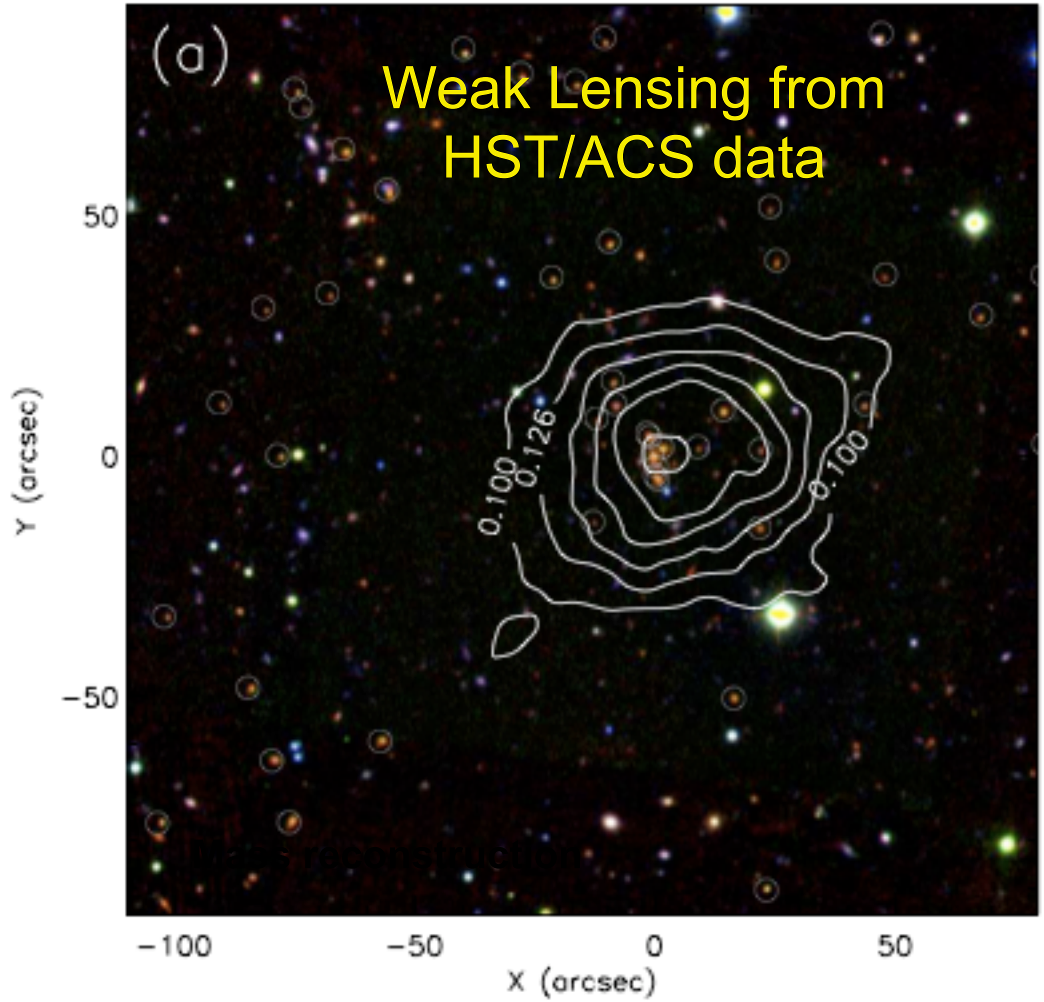




- Lensing observations of massive clusters can directly test ΛCDM scenario on cluster (~30-1000 kpc) scale
  → unique probe of inner DM profile → can constrain DM properties
- Using a variety of complementary probes which cover 3 decades in mass, degeneracies (inner slope, concentration and M*/L) are mitigated
- **High S/N X-ray observations are essential to decouple the baryon gaseous component from the total lensing mass**
- How baryonic physics affects the shape of the inner DM potential is poorly known

Mass distribution in the most distant clusters
XMM2235 at z=1.39

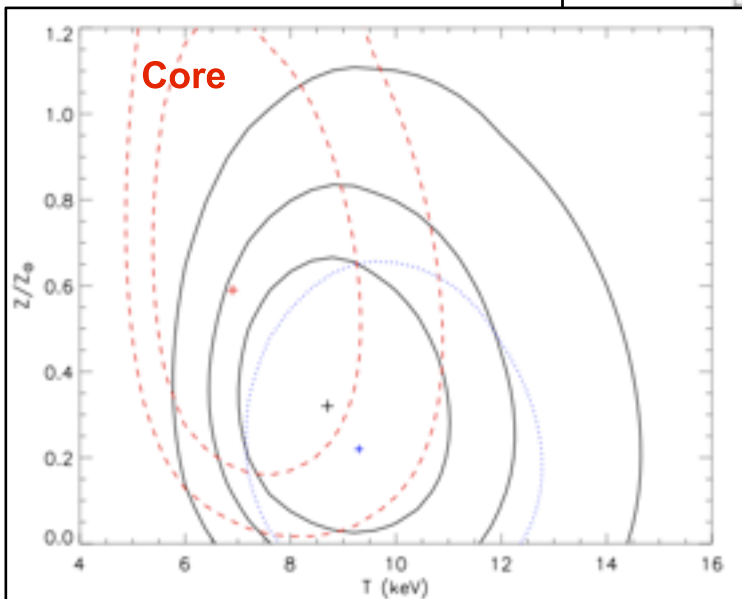


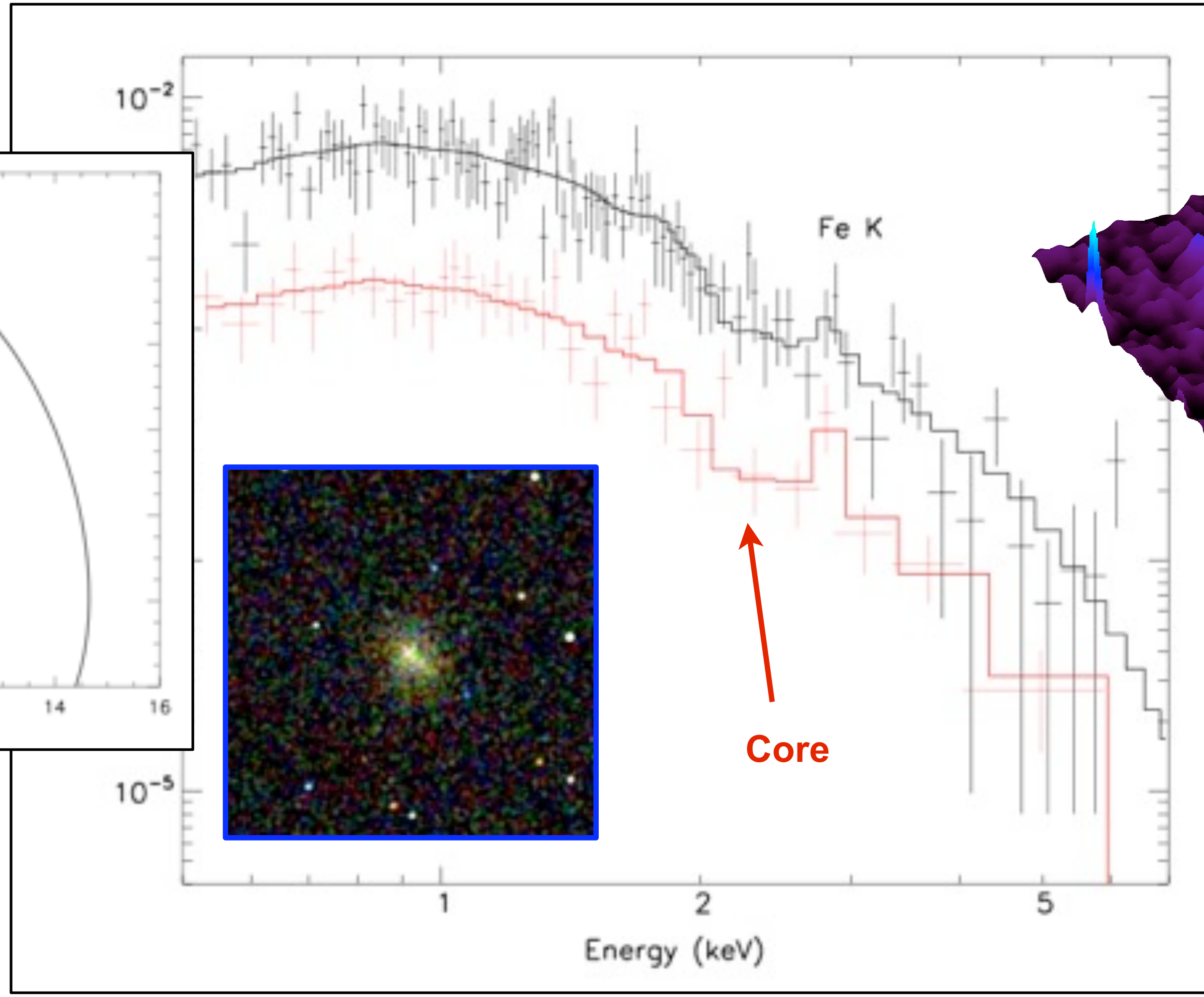


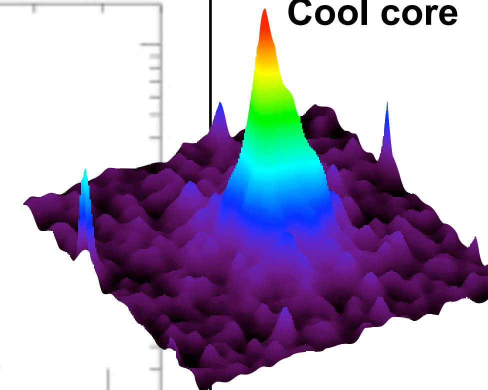
Jee, PR et al. 09

- Chandra X-ray traced out to 1 arcmin
- Shear signal detected out to ~140" (max >8σ)

190 ksec Chandra Observations of XMM2235 at z=1.4
(~15 ks with IXO)







Rosati et al. 09

➡ The ICM is already enriched at local values at z=1.4

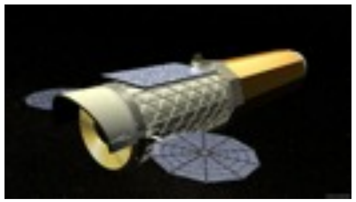
➡ Metal enrichment completed by z~ 2.5

$$Z = 0.32^{+0.19}_{-0.22}\, Z_{\odot}$$

$$Z = 0.59^{+0.29}_{-0.37}\, Z_{\odot}$$

IXO-ELT-Euclid synergy flow
DM & Baryonic Mass Distribution

IXO



Baryon mass distribution (at high-z)
Combined X-ray/WL masses

E-ELT

Innermost mass profile

Redshifts of strong lensing features

DM Mass distribution on cluster scale

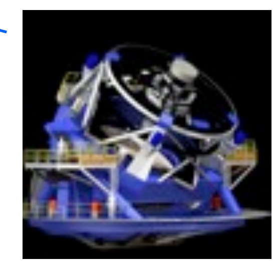
Euclid

W.lensing masses (low-z)

Dynamical masses (?)

WL masses profile (z<1)

LSST



Discovery of strong-Lensing systems:

~10^5 Galaxy-galaxy lenses,

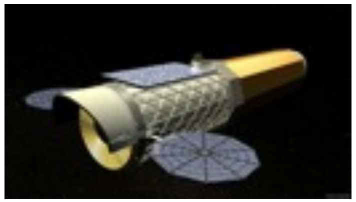
~10^3 galaxy-quasar lenses,

5000 strong lensing arcs in clusters

IXO-ELT-Euclid synergy flow

Calibration of cluster masses

IXO



- Total/gas mass, Y_X (high-z)
- f_{gas} vs radius
- gas velocity map, turbulence
- $b_T=(kT/\mu m_p)/\sigma^2_{DM}$, thermalization

Note: 5" resolution is essential to resolve the core

Mass proxies for Cosmological applications

X-ray/SZ cluster samples

Opt/NIR wide surveys

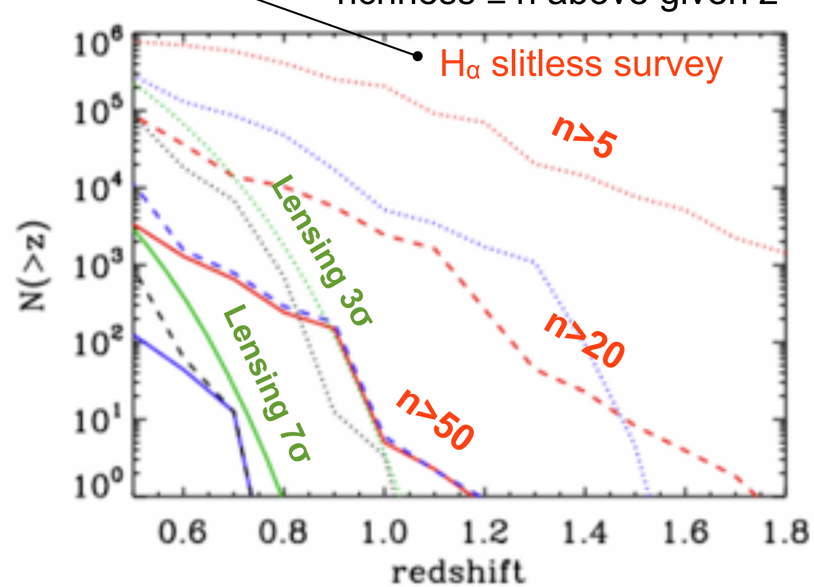
SPT
eROSITA
WFXT
LSST, PanSTARRS

Euclid

W.lensing masses (low-z)

Dynamical masses (?)
10,000 clusters at z<1

Number of clusters with richness ≥ n above given z



Credit: A.Biviano

Total Number of groups/clusters

n	N_{tot}
> 5	~220,000
>20	~5,000
>50	~100

Outlook

- Complementarity and Synergy with E-ELT and Euclid enhance the science breadth of IXO, particularly in the area of structure formation (from galaxy to cluster and cosmological scales)
- Strong coordinated programs on
  - Galaxy-BH coevolution
  - Proto-cluster formation
  - Cosmic Web of Baryons
- Target finder: IXO can in some cases find its own targets (high-z AGN), however wide area surveys are needed to fully exploit its capabilities and enable a large number of science cases
- The combination of IXO with *X-ray* missions designed for wide&deep surveys at similar angular resolution (WFXT) can only strengthen its role of multi-purpose observatory and provide momentum to build it